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PERFORMANCE EVALUATION OF DISTRIBUTARY CANALS IN SOUTHERN ALBERTA

by

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March 1984

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ABSTRACT

This report introduces, in a qualitative manner, the concepts necessary to critically examine the performance of irrigation conveyance systems. The operation of a small distributary canal, typical of those found in Southern Alberta, is examined in detail. Performance criteria useful for evaluating the physical and operational characteristics of irrigation conveyance systems is also introduced. Using the results of the examination of the distributary canal and the performance criteria of sixteen significant factors affecting irrigation conveyance system performance are introduced.

ACKNOWLEDGEMENT

The author wishes to adknowledge the funding of this research by grants from the Research Management Division of Alberta Environment and research contracts from the Planning Division of Alberta Environment.

1.0 Introduction

This report introduces the concepts necessary to identify and describe the complex relationships between the numerous factors which influence the irrigation water conveyance process and irrigation conveyance system performance. This is achieved through a detailed but qualitative examination of the operation of the smaller distributary irrigation canals typical of those found in Southern Alberta. A more thorough discussion and quantitative analysis of the concepts presented in this report may be found in Manz (1984).

2.0 General Description of the Physical and Operational Characteristics of Distributary Canals

Distributary canals deliver water from a larger supply canal or storage facility directly to the farmer consumers. A sketch of a typical distributary canal which uses a lateral canal for its water supply is shown in Figure 1. Water is released into the distributary canal through a diversion structure called the distributary off-take. This water is made available to the farmers through diversion structures called quaternary off-takes. A distributary canal may possess several quaternary off-takes even though only two are illustrated in Figure 1. The canal which transports the water from the distributary off-take to the quaternary off-takes may vary, physically, in terms of its length, slope, cross-sectional shape and size, and conditions; and, also in terms of the nature of the distributed water loss/gain processes which may be operative. (An example of a distributed water loss process is seepage outflow. An example of a distributed water gain process is precipitation inflow.) Included in what is called the canal are a variety of specialty structures which are used to control canal grade, to cross under or over obstacles, to facilitate the transition from one type of canal to another, to remove trash or to facilitate flow measurement. If properly designed, these structures will not adversely or significantly affect distributary canal performance and are not shown in Figure 1. Depth control structures, (frequently called check-structures), are used to provide the necessary depth of water for the operation of

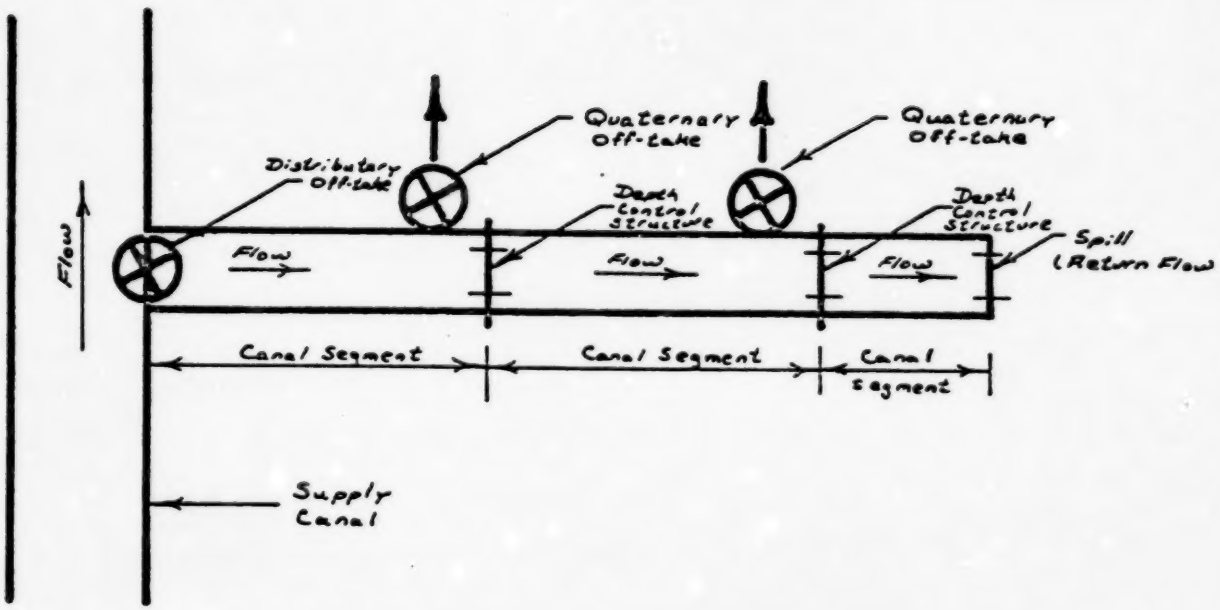

Figure 1. Sketch of a Typical Distributary Canal

upstream quaternary off-takes. Water diverted into the distributary canal, which is either not delivered to farmers or otherwise lost enroute to the operating quaternary off-take(s), is called spill. Note that spill occurs immediately after the most downstream operating quaternary off-take. Spilled water will leave the canal either as seepage or as surface return flow.

3.0 Performance Evaluation of Distributary Canal Operations

The descriptors used to evaluate the performance of distributary canal operations are based on the generally accepted ideal of obtaining maximum water conservation while completely satisfying farm irrigation water needs.

3.1 Conveyance Efficiency

Conveyance efficiency, e_c, is defined by the relation:

$$e_c = \frac{\forall_f}{\forall_I} \qquad - (1)$$

where: $\forall_f$ is the volume of water delivered to farmers and actually applied to the land over a specific time period; and,

$\forall_I$ is the volume of water diverted through the distributary off-take from the lateral canal for eventual application to the land over the same time period.

Conveyance efficiency considers all factors which determine the performance of a canal used to deliver water to farmers for application to the land.

3.2 Physical Conveyance Efficiency

Physical conveyance efficiency, e_f, is defined by the following relation:

$$e_f = \frac{\forall_I - (V_s + \forall_e + \forall_t)}{\forall_I} \qquad - (2)$$

where $\forall_s$, $\forall_e$ and $\forall_t$ are the volumes of water lost from the canal by seepage,

evaporation and transpiration processes respectively over a specific time period. Physical conveyance efficiency is a measure of the relative magnitude of distributed loss rates associated with a particular canal.

3.3 Unit Physical Conveyance Efficiency

Unit physical conveyance efficiency, u_f, is defined as the physical conveyance efficiency of a canal of unit length, (eg. 1 kilometer). The use of this term permits the otherwise difficult exercise of comparing the performance of physically different canals.

3.4 Operational Efficiency

Operational efficiency, e_o, is defined by the relation:

$$e_o = \frac{\Psi_f + (\Psi_s + \Psi_e + \Psi_t)_{min}}{\Psi_I} \qquad - (3)$$

where $(\Psi_s + \Psi_e + \Psi_t)_{min}$ is the minimum distributed loss associated with delivering the volume of water, Ψ_f, to the farmer for application to the land. Operational efficiency is a measure of the canal operator's ability to minimize distributed water losses and spillage during the course of meeting the farmer's actual water demands.

3.5 Maximum Conveyance Efficiency

The maximum attainable conveyance efficiency, $e_{c,max}$, will occur when the volume of spillage equals zero and the volume of distributed losses incurred while making the water delivery to the farmer(s) are at a minimum. Maximum conveyance efficiency is defined by the relation:

$$e_{c,max} = \frac{\forall_f}{\forall_{I,min}} = \frac{\forall_f}{\forall_f + (\forall_s + \forall_e + \forall_t)_{min}} \quad - (4)$$

It is important to note that the volume of inflow to the canal is at a minimum when the canal is operating at maximum conveyance efficiency.

3.6 Example Demonstrating the Utility of Various Efficiency Terms

Consider the following table which compares the efficiencies associated with unlined canals, lined canals and closed pipeline systems.

Table 1. Comparison of the Expected Performance of Canals and Pipilines

		e_c	e_f	u_f	e_o	$e_{c,max}$
1.	unlined canal	less than 1	less than 1	less than 1	less than or = 1	less than 1
2.	lined canal	less than 1	= 1	= 1	less than or = 1	= 1
3.	closed pipeline	= 1	= 1	= 1	= 1	= 1

4.0 Description of Conveyance System Operations

4.1 Introduction

The significance of the factors which collectively determine the performance of distributary canal operations may best be demonstrated using an example. The example chosen, though typical, represents only one of the great variety of distributary canal physical or operational types found in Southern Alberta. Considerably more complex and simpler distributary canals may be found; however, all of the major elements influencing distributary canal performance are included in the example presented.

4.2 The Example

The particular distributary canal to be considered is illustrated in Figure 2. Note that the steps required to operate the canal in order to deliver water from the storage facility to farmer no. one through quaternary off-take no. one are shown as well. Each of the steps are numbered and are discussed as follows:

Step 1. The canal operator receives notice that the farmer no. one requires water.

Step 2. He generates an estimate of the farmer's actual water requirements.

Step 3. The canal operator estimates the magnitude of distributed losses which will occur while the water is transferred from the distributary off-take to quaternary off-take no. one.

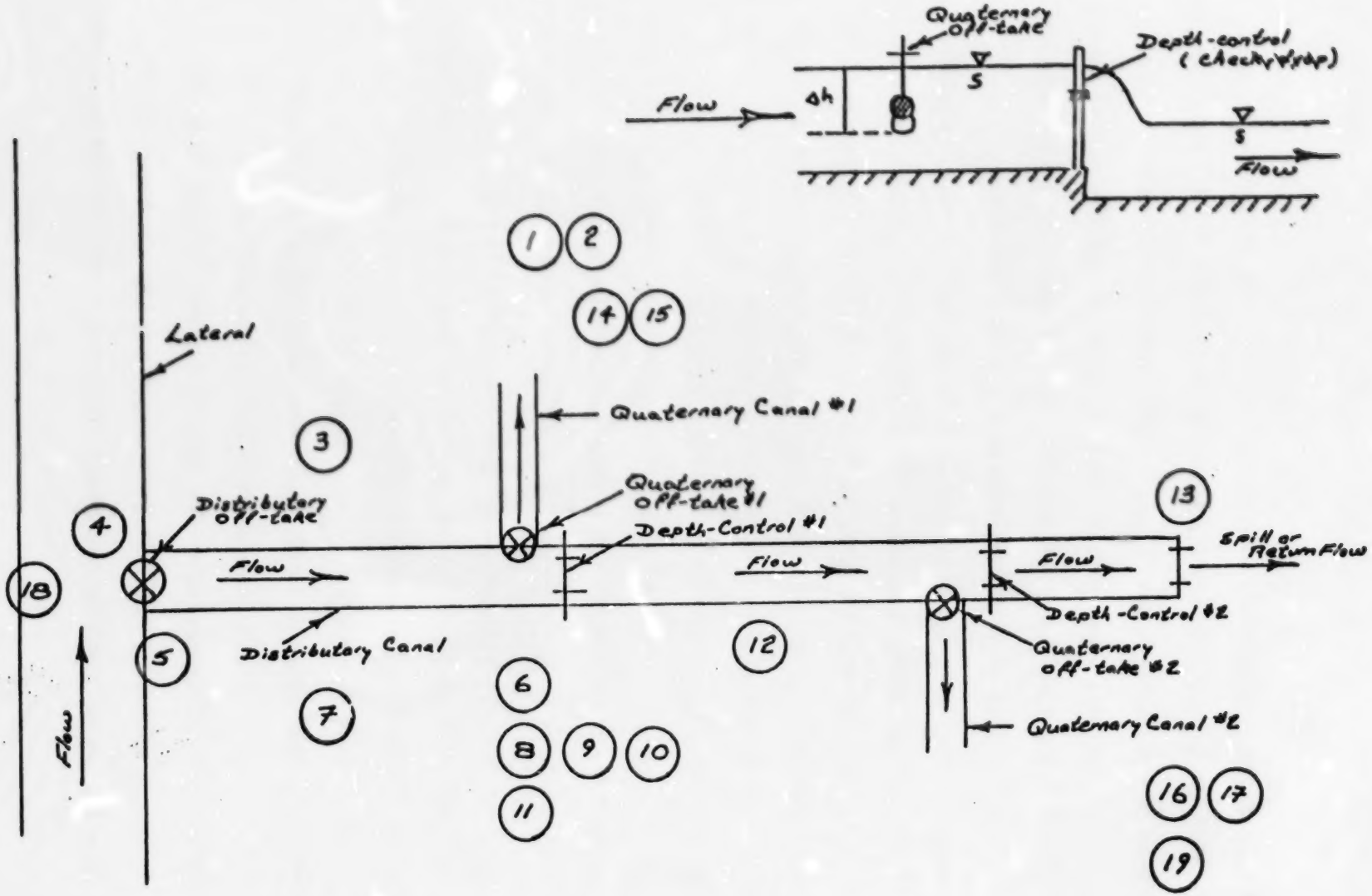

Figure 2. Distributary Canal Operations

Step 4. The canal operator estimates the magnitude of the required release into the distributary canal.

Step 5. The canal operator operates the distributary off-take and diverts water into the distributary canal. The actual amount diverted into the canal will likely differ from his objective due to imprecise distributary off-take operations.

Step 6. The canal operator will operate the depth-control structure immediately downstream of quaternary off-take no. one to ensure that there is adequate depth of water in the canal to operate quaternary off-take no. one. (eg. He will raise the height of the weir if it is a weir-type depth-control structure.)

Step 7. The water actually released into the canal will be reduced by unknown distributed loss rates, which are a function of the canal hydraulic and hydrologic characteristics at the time the canal is operated and by the backwater effects caused by the operation of the depth-control structure.

Step 8. When the operator is sure that steady-state conditions are achieved at quaternary off-take no. one, he will operate quaternary off-take no. one and make the delivery to the farmer.

Step 9. The farmer is ready to accept this delivery and extracts his water application needs from the delivery.

Step 10. Water delivered to the farmer in excess of his needs is spilled by the farmer into some available drainage system.

Step 11. Water reaching quaternary off-take no. one and not delivered

to the farmer is allowed to spill down the distributary canal.

Step 12. As the spilled water passes down the distributary canal, its volume is reduced by additional distributed losses incurred while enroute.

Step 13. Spilled water which reaches the end of the canal is ejected into an available drainage system and is called surface return flow.

Not shown in Figure 2 are the procedures the canal operator may use to reduce excessive spill. These steps are described as follows:

Step 14. After a period of time farmer no. one may complain of excess delivery to the canal operation. (With the use of sprinkler irrigations systems, excess deliveries are preferred to short-falls.)

Step 15, The canal operator will assess farmer no. one's complaint and reduce delivery to him by operating quaternary off-take no. one.

Step 16. Additional distributary spill will occur.

Step 17. The canal operator assesses the spill. (Usually, he assesses the volume of surface return flow.)

Step 18. The canal operator reduces the diversion into the distributary canal by operating the distributary off-take.

Step 19. After a period of time, the canal operator will reassess the spill and may repeat Step 17.

If the flow through the distributary off-take remains constant and if the farmer's water consumption rate continues unchanged, the delivery will continue until the farmer requests it stopped.

4.3 Detailed Analysis of the Example of Distributary Canal Operation

It is instructive to examine, in detail, the individual processes which have contributed to or have directly caused the various flow rates which may be observed during the course of the water delivery. Each step is analyzed as follows:

Step 1. The farmer usually does not know how much water he needs. He simply knows he needs water and has paid for the priviledge to receive it. He communicates his "needs" for water to the canal operator.

Step 2. The canal operator must estimate the farmer's water requirements. He will do this by examining the farmer's irrigation system and arrive at an estimate which he is sure will more than satisfy the farmer's requirements. If the farmer has irrigated earlier in the same season, this process may be simplified. Flow measurement equipment would be useful for this purpose; however, it is not normally available. The canal operator's estimate of the farmer's water needs may be expressed in equation form as follows:

$$F_{1,est} = F_{1,act} \pm error_{f1,est} \qquad - (5)$$

where: $F_{1,est}$ = canal operator's estimate of farmer no. one's water needs;

$F_{1,act}$ = farmer no. one's actual water needs; and,

$error_{f1,est}$ = difference between the actual farm water requirements and the canal operator's estimate.

Step 3. The canal operator must estimate what his losses will be between the distributary off-take and the quaternary off-take. He has no way of knowing exactly what this is unless he has operated the canal in the recent past and has accurate flow measurement equipment at his disposal. His procedure for estimating the losses may assume the form:

$$L_{f1,est} = k\, F_{1,est} \qquad - (6)$$

where: $L_{f1,est}$ = estimate of distributed water losses between losses between distributary off-take and quaternary off-take no. one; and,

k = some fixed proportion of the estimated farm water requirements.

Step 4. The canal operator estimates the quantity of water he must divert into the distributary canal using the relation:

$$Q_{1,est} = F_{1,est} + L_{f1,est} \qquad - (7)$$

where $Q_{1,est}$ = estimate of required water diversion through the distributary off-take.

Step 5. The canal operator will begin the delivery by operating the distributary off-take so as to release $Q_{1,est}$ into the distributary canal. The precision with which this diversion

will be made will depend on the quality of flow control he has over the diversion structure; that is, his ability to select the rate of flow desired and the magnitude of the error made in associating flow rates with particular diversion adjustments. The actual diversion made into the canal may be represented by the following equation:

$$Q_{1,act} = Q_{1,est} \pm error_{del,dist} \quad - (8)$$

where $error_{del,dist}$ is the error made in the diversion associated with the operation of the distributary off-take.

Step 6. Having made the diversion into the canal, the canal operator will then raise the height of the weir in the depth control structure, (usually a weir-type check), so as to ensure that there will be sufficient water depth in the canal to satisfactorily operate quaternary off-take no. one.

Step 7. The water is moving down the distributary canal in the form of a positive surge wave. If the canal was dry before the water was released, the progress of the surge wave will be much slower than if the canal already had water flowing through it. The slower progress is a consequence of the process called canal "priming" or simply the process of wetting the soil material the canal is made of. Seepage into the canal perimeter is rapid at first but quickly reduces to some stable value which is function of the canal soil properties and the characteristics of the ground water regime the canal water

seeps towards. (ie.; the canal is assumed to be unlined.) The surge will reach the depth-control structure and begin filling up the canal. Seepage from the canal will increase as the back-water effects progress upstream. Eventually, water will start flowing over the check and continue down the canal. Depending on the length of canal between the distributary off-take and the quaternary off-take, a considerable period of time must pass, (several hours), before even approximate steady-state conditions are achieved. Water flowing past the depth control structure is spilled.

(The seepage of water from a canal is a highly variable and dynamic process which requires considerable field information simply to observe. It is known, however, that the volume of seepage losses which will occur are a function of the depth of water in the canal, the material used to construct the canal, the shape and size of the canal cross-section and the characteristics of the subsurface soil and groundwater regime.

If the vegetation adjacent to the canal extracts water either directly or indirectly from the groundwater, fluctuations in seepage rate from the canal may be observed. The fluctuations will correspond with periods of increased or decreased plant transpiration. During daylight hours when plant transpiration is at a maximum, the groundwater table will be drawn down, in

turn causing increased seepage from the canal. At nightfall, transpiration will essentially cease, the groundwater table will rise and seepage from the canal will decrease. The impact these fluctuations have on canal flow increases with the length of canal and may become appreciable. If the canal is subject to these fluctuations in seepage, the operator will divert enough water to ensure sufficient delivery during periods of peak seepage rates. Obviously, during periods of low seepage rates, considerable water may be spilled.

If the magnitude of the fluctuations is significant, it will also interfere with the operation of the quaternay off-takes by causing the diversion to the farmers to fluctuate inversely to the seepage rate from the canal. (This is true for all types of quaternary off-takes whose through-flow is a function of upstream canal depth.) The canal operator will attempt to minimize the effects of the fluctuations by increasing the height of the weir in the check well beyong normal levels. (The resulting increase in the depth of water upstream of the check will result in increased seepage rates.) The rate of flow of water in the distributary canal at the quaternary off-take no. one may be estimated by the relation:

$$Q_{f1,act} = Q_{1,act} - L_{f1,act} \qquad - (9)$$

where $L_{f1,act}$ is the actual distributed loss between the

distributary off-take and quaternary off-take no. one.

Step 8. Once the canal operator believes that steady-state conditions have been approximated, he will operate the quaternary off-take to divert the quantity of water he believes the farmer requires. It should be emphasized that the canal operator will not remain at the quaternary off-take waiting for the steady-state conditions to develop. Rather, he will estimate the time required and perhaps leave to perform other duties and return at the appropriate time. The actual diversion the canal operator will make to farmer no. one may be represented by the following equation:

$$F_{1,del} = F_{1,est} + error_{del,quat} \qquad - (10)$$

where $F_{1,del}$ = actual delivery to farmer no. one; and,

$error_{del,quat}$ = error in the diversion associated with the operation of the quaternary off-take.

Step 9. The farmer must be prepared to accept the water delivery once it arrives. If he is not ready to receive the water or has no provision to temporarily store it, the water is spilled into some convenient drainage system by the farmer. Water in excess of the farmer's actual need will also be spilled. If the canal operator does not divert sufficient water to the farmer, the farm water application system may not be operable at all, (eg. sprinkler irrigations systems), and all water delivered to the farmer may be spilled. This condition will

continue until the diversion to the farmer can be increased. For this reason, the canal operator normally ensures that diversions to farmers are in error on the positive side. Farm spill may be estimated using the relation:

$$\text{Farm spill} = F_{1,del} - F_{1,act} \qquad - (11)$$

Step 11. Water not delivered to the farmer continues past the depth-control structure and is spilled. This spill may be estimated using the relation:

$$\text{Canal spill} = Q_{fl,act} - F_{1,act} \qquad - (12)$$

Step 12. As the spilled water continues down the canal, significant fractions of it will seep through the canal in a manner similar to that described in Step 7. If the rate of spill is relatively low, all the spilled water may leave the distributary canal as seepage; that is, despite the fact that there is spill, there will be no surface return flow.

Step 13. Distributary canal spill which reaches the canal terminus is discharged into some available surface drainage system. The rate of surface return flow from the distributary canal is given by the equation:

$$Q_{\text{return flow}} = \text{canal spill} - L_{fl,outlet} \qquad - (13)$$

where $L_{fl,outlet}$ is the distributed loss between quaternary off-take no. one and the canal terminus.

Step 14. If farmer no. one's delivery is either too excessive or worse, insufficient, he will communicate his dissatisfaction to the canal operator. The communication process may require a considerable period of time depending on the communications system operative within the particular conveyance system.

Step 15. Upon receipt of farmer no. one's complaint, the canal operator will inspect the delivery of water through farmer no. one's quaternary off-take. He will first ensure that the integrity of all of his previous operations have been maintained. Having performed this exercise, he will either increase or decrease the diversion to the farmer by operating the quaternary off-take. The increase of decrease is rarely performed in an absolute sense. The canal operator will attempt to incrementally change the rate of diversion by some small proportion of the existing flow rate. The flow rate through the quaternary off-take after the canal operator has completed his adjustment may be given by the equation:

$$F_{1,del} = (1 \pm C_{f1}) F_{1,del} \qquad - (14)$$

where C_{f1} is the adjustment factor, usually less than or equal to 0.1.

Step 16. If the action of the canal operator was intended to reduce farm spill, the result of his actions would be to increase distributary canal spill by the same quantity he reduced farm spill.

Step 17. If the canal operator believes the spill to be excessive, he will decrease the diversion through the distributary off-take. This decision will be based on the management policy concerning distributary canal spill.

Step 18. The canal operator will adjust the distributary canal off-take in a manner similar to the adjustments made to the quaternary off-take. It is important to note that flow changes made at the distributary off-take will eventually alter all flow rates and diversions in the distributary canal.

Step 19. After some period of time, even if no complaints from farmer no. one has been recieved, the canal operator would inspect the flow of water at the canal terminus or at some location downstream of the operating quaternary off-take. Depending on management policy concerning canal spill; and the canal operator's estimate of what the spill actually is, he may or may not attempt to reduce it by decreasing the diversion through the distributary off-take. If the canal operator considers the spill to be within acceptable limits, the diversion through the distributary off-take will be maintained. The delivery to farmer no. one will continue until he requests it terminated.

The termination procedure consists of reducing flow at the distributary off-take, terminating the delivery thgough the quaternary off-take and restoring the depth-control structure

to pre-delivery conditions.

5.0 Identification of Factors which Determine Distributary Canal Performance

5.1 Introduction

The level of distributary canal performance is a function of the volume of distributed losses, farm spill and canal spill incurred during the course of making the farm water deliveries. The factors which govern the magnitude of these losses may be identified by considering the description of distributary canal operations presented in Section 4.0 and the hydraulics of the processes affected.

5.2 Distributed Losses

Distributed losses include seepage, evaporation and transpiration. Direct evaporation and transpiration losses from the canal are usually not appreciable and will not be discussed further. The factors which determine the volume of seepage losses from the canal are as follows:

- permeability characteristics of the canal; bottom and sidewalls
- permeability characteristics of the underlying soil and rock;
- characteristics of the groundwater regime ⟹ position of groundwater tab with respect to canal bottom
- canal shape and size;
- length of the individual canal segments; and,
- depth of water in the canal.

The first five of the factors are largely determined at the time the canal is designed and constructed. The depth of water in the canal, however, is a function of the characteristics of water flow. also a design parameter!

The factors which affect the characteristics of water flow in the canal

are as follows:

- the physical condition of the canal which includes:
  - shape of canal cross-section,
  - size of canal cross-section,
  - roughness of canal,
  - slope of canal bottom, and
  - length of canal segment.
- the flow rate in individual canal segments which are a function of:
  - the actual discharge of water through the distributary off-take which is in turn a function of:
    - actual farm water demands,
    - ability of the canal operator to estimate the actual farm water demand,
    - actual distributed water losses,
    - ability of canal operator to estimate actual distributed water losses,
    - depth of water in lateral canal or storage facility which supplies the distributary canal,
    - flow of water in the lateral canal, if a lateral canal is being used for water supply,
    - ability of the canal operator to control distributary off-take,
    - method used to perform the fine adjustments to flow through the distributary off-take,
    - frequency of operation of the distributary off-take,
    - knowledge of canal spill, and
    - management policy concerning canal spill.

(It should be noted that several of the factors listed relate to a limited number of the many types of diversion structures that are used as distributary off-takes.)

- the actual delivery of water through quaternary off-takes which include:
  - actual farm water demand,
  - ability of the canal operator to estimate the actual farm water demand,
  - ability of the canal operator to control the quaternary off-take,
  - actual depth of water in the distributary canal serving the quaternary off-take,
  - flow of water in the distributary canal serving the quaternary off-take,
  - canal operator's ability to predict the time to steady-state flow conditions at the quaternary off-take,
  - actual time before steady-state conditions achieved and quaternary off-take operated,
  - satisfaction of the farmer with the water delivery,
  - frequency of operation of the quaternary off-take, and
  - method used by canal operator to perform fine adjustments to quaternary off-take.

(It should be noted that several of the factors listed are peculiar to only a limited number of types of diversion structures that are used as quaternary off-takes.)

- the operation of depth-control structures which includes:
  - estimated water delivery to be made through the adjacent upstream quaternary off-take,
  - observed or predicted flow required past the depth-control structures,
  - depth of water required before proceeding to operate the quaternary off-take, and
  - the ability of the canal operator to control the depth-control structure.

(Note that the factors cited relate to only one of several types of depth-control structures that may be employed.)

5.3 Farm Spill

Farm spill is a function of two primary factors:

1. actual farm water demand, and
2. actual farm water delivery.

The factors which govern actual farm water delivery are listed in the previous discussion on seepage. Note also that since two of the factors which govern the actual farm water delivery are the depth of flow and the rate of flow of the water in the distributary canal, virtually all of the factors which affect the characteristics of water flow will indirectly affect farm water spill.

5.4 Canal Spill

Canal spill is a function of three primary factors:

1. actual farm water deliveries,
2. actual distributed losses; that is, seepage, and
3. actual release of water through the distributary off-take.

Considering the previous discussion on seepage, it is apparent that canal spill is a function of all the factors which determine the nature of the flow of water in the distributary canal.

6.0 Sensitivity of Distributary Canal Performance to the Factors which Govern the Magnitude of Seepage, Farm Spill and Canal Spill Losses

It is clear that the rate of water loss by seepage, farm spill and canal spill are very complex but different functions of the distributary canal, physical and operational characteristics, the characteristics of the physical environment the canal is operated within and the nature of the water demands place on the canal. Detailed consideration of the impact of each of the numerous factors cited in Section 5.0 of this report are beyond the scope of the present study; however, the relative sensitivity of distributary canal performance to several of the more significant factors is discussed.

The results of the analysis are summarized in Table 2. Sixteen factors which govern distributary canal performance are related to the volume of seepage losses, farm spill and canal spill, and the relative impact these losses have on unit physical conveyance efficiency, physical conveyance efficiency, operational conveyance efficiency, conveyance efficiency and maximum conveyance efficiency. The impact the various factors have on the efficiency terms is ranked on a scale of one to three which may be interpreted as significant, moderate and minimal. If the factor has no affect, this is indicated as well. This analysis should be reviewed in light of the specific example of distributary canal operations discussed in Section 4.0 of this report. Each factor listed is Table 2 is discussed as follows:

1. Permeability of canal construction material.

Canals constructed of higher permeability materials will exhibit higher

Factor	Volume Seepage Loss	Volume Farm Spill	Volume Canal Spill	u_f	e_f	e_o	e_c	$e_{c,max}$
1. permeability of canal construction material - increase.	increase	const.	const.	decrease 1.	decrease 1.	increase 3.	decrease 2.	decrease 1.
2. length of individual canal segments - increase.	increase	const.	const.	no affect	decrease 1.	increase 3.	decrease 2.	decrease 1.
3. slope of canal bottom - decrease.	increase	const.	const.	decrease 1.	decrease 1.	increase 3.	decrease 2.	decrease 1.
4. ratio of actual discharge to canal design capacity - increase.	increase	const.	const.	increase 1.	increase 1.	increase 3.	increase 2.	increase 1.
5. roughness - increase.	increase	const.	const.	decrease 1.	decrease 1.	increase 3.	decrease 3.	decrease 1.
6. error in estimate of farm water requirements - increase.	increase	increase	increase	increase 3.	increase 3.	decrease 1.	decrease 1.	no affect
7. complexity of operations	increase	increase	increase	increase/ decrease 3.	increase/ decrease 3.	decrease 1.	decrease 1.	no affect
8. error in estimating distributed water loss - increase.	increase	const.	increase	increase 3.	increase 3.	decrease 1.	decrease 1.	no affect

Table 2. Sensitivity of Distributary Canal Performance to Factors which Govern the Magnitude of Seepage, Farm Spill and Canal Spill.

Factor	Volume Seepage Loss	Volume Farm Spill	Volume Canal Spill	u_f	e_f	e_o	e_c	$e_{c,max}$
9. error in operating the distributary off-takes - increase.	increase	const.	increase	increase 3.	increase 3.	decrease 2.	decrease 2.	no affect
10. frequency of operation of distributary off-takes - increase.	decrease	const.	decrease	decrease 3.	decrease 3.	increase 1.	increase 1.	no affect
11. error in operating quaternary off-takes - increase.	no affect	increase	decrease	no affect	no affect	no affect	no affect	no affect
12. error in predicting time to steady - state - increase.	no affect	const.	increase	no affect	no affect	decrease 3.	decrease 3.	no affect
13. control of depth of water upstream of depth-control structure - increase.	increase	const.	const.	decrease 1.	decrease 1.	decrease 2.	decrease 1.	no affect
14. fluctuation of depth of water in supply canal - increase.	increase	increase	increase	variable increase 3.	variable increase 3.	decrease 1.	decrease 1.	no affect

Table 2. Sensitivity of Distributary Canal Performance to Factors which Govern the Magnitude of Seepage, Farm Spill and Canal Spill.

Factor	Volume Seepage Loss	Volume Farm Spill	Volume Canal Spill	u_f	e_f	e_o	e_c	$e_{c,max}$
15. fluctuation of seepage from distributary canal - increase.	increase	increase	increase	variable increase 3.	variable increase 3.	variable decrease 1.	decrease 2.	variable decrease 2.
16. technical competence of canal operators - increase.	decrease	decrease	decrease	increase 1.	increase 1.	increase 1.	increase 1.	no affect

Table 2. Sensitivity of Distributary Canal Performance to Factors which Govern the Magnitude of Seepage, Farm Spill and Canal Spill.

rates of seepage loss. If farm and canal spill are held constant and farm water deliveries are maintained, the unit physical conveyance efficiency, physical conveyance efficiency, and the maximum conveyance efficiency will decrease significantly. Conveyance efficiency will not decrease as rapidly. Operational efficiency may actually increase if the volume of water diverted into the distributary canal is not increased. This apparently anomolous change in operational efficiency occurs because the minimum seepage loss incurred while making the delivery has increased while the diversion into the distributary canal has not. The implication is that the canal operator has more accurately estimated distributary canal losses.

2. Length of individual canal segments.

The effect of longer canal segments is largely to increase the seepage loss. If farm and canal spill are held constant and the farm water deliveries are maintained, the effect will be similar to that of increased canal permeability except that unit physical conveyance efficiency will remain unaffected.

3. Slope of canal bottom.

Canals constructed with smaller bed slopes will exhibit greater depths of flow than canals of similar cross-section and flow rate constructed with steeper bed slopes. This will result in increased seepage loss without necessarily affecting farm or canal spill. The effect on the performance of the canal is similar to increasing the permeability of the canal construction material, Factor no. one.

4. Ratio of actual flow rate to canal design capacity.

The actual flow rates in distributary canals are not normally at or even near design capacity but will vary depending on the water demand placed on the canal. Though the volume of seepage increases with depth of flow of the water in the canal, the flow rate will increase at a much greater rate with increased depth of flow. That is, the relative magnitude of the seepage losses from the canal decrease with increased flow rates despite the increased volume of seepage losses. All efficiency terms will increase as this ratio increases.

5. Roughness of the canal.

As canal roughness increases, the velocity of the water decreases. Therefore, the depth of flow of the water must be increased to maintain desired flow rates. The increase in the depth of water will result in a greater volume of seepage for the same rates of flow. If farm and canal spill are maintained, unit physical conveyance efficiency, physical conveyance efficiency, conveyance efficiency and the maximum conveyance efficiency will decrease. Operational efficiency may increase slightly for reasons cited in the discussion of Factor no. one.

6. Error in estimating farm water requirements.

Errors in estimating farm water requirements are usually positive so as to ensure that adequate water is available to make the deliveries. The error, however, results in more water being diverted through the distributary off-take than is required to satisfy the farmers' needs. The volume of seepage will increase; however, for reasons cited in the discussion of Factor no. four, slightly improved physical and unit physical conveyance

efficiencies may be observed. The surcharge of water released into the canal will result in significant increased spill which is reflected by significantly decreased operational efficiency and conveyance efficiency. The maximum conveyance efficiency will not be affected.

7. Complexity of operations.

The more farm water deliveries which must be started or stopped within a single operational cycle, the more complex the operations required by the canal operator. Generally, this will result in increased spill and seepage. The maximum conveyance efficiency will not be affected; however, operational and conveyance efficiencies will definitely decrease.

8. Error in estimating rate of seepage loss.

Errors in estimating the rate of seepage loss are usually positive in order to ensure that there is adequate water supply for farm water deliveries. This surcharge will result in a greater volume of seepage loss but for reasons cited in the discussion of Factor no. 4, the unit physical and physical conveyance efficiencies will slightly increase. Operational efficiency and conveyance efficiency may be significantly decreased. Maximum conveyance efficiency will remian unaffected

9. Error in operating distributary off-takes.

Errors in the operation of distributary off-takes are usually positive in order to ensure that there is adequate water available for farm water deliveries. This will result in increased seepage; and more significantly, increased canal spill. Unit physical and physical conveyance efficiencies will increase slightly for reasons cited in the discussion of Factor no. 4;

however, both operational and conveyance efficiencies may be significantly decreased. Maximum conveyance efficiency will not be affected.

10. Frequency of operation of distributary off-take.

The operations alluded to include the evaluation of flow through the off-take and its correction if required. The more frequent the evaluation/correction operation is, the less volume of seepage loss and canal spill will be incurred. This will result in slightly decreased unit physical and physical conveyance efficiencies for reasons cited in the discussion of Factor no. 4. and significant increases in operational and conveyance efficiency. The maximum conveyance efficiency will not be affected.

11. Error in operating quaternary off-takes.

The error in operating quaternary off-takes is usually positive to ensure that there is adequate water delivered to the farmer. Though farm spill will increase as this error increases, canal spill will decrease by the same amount, (and vice versa). As a consequence, all efficiencies defined will remain constant until the volume of surcharge through the distributary off-take is reduced.

12. Error in predicting time to steady-state at quaternary off-take.

This error is usually positive since the canal operator wants to reduce the frequency of quaternary off-take adjustment. The result is a temporary increase in canal spill. If this spill is considered relative to the volume of water normally transported over the entire delivery cycle, it will be noted that it is relatively insignificant. Only slight decreases in operational and conveyance efficiency would be expected.

13. Controlled depth of water upstream of depth-control structures.

The depth of water upstream of depth-control structures is regulated in order to facilitate the operation of quaternary off-takes. Usually, the deeper the water is, the less sensitive to error is the operation of the quaternary off-take. The habit of abnormally increasing the depth of water over the quaternary off-take is called "high-checking". The result of the use of this technique of depth-control is to increase the volume of seepage from the canal as far upstream as the backwater effect occurs. Depending on the severity of the "high checking", unit physical and physical conveyance efficiencies and conveyance efficiency may be significantly reduced. Operational efficiency will decrease slightly because of the increased seepage. The maximum conveyance efficiency will be unaffected.

14. Fluctuations of the depth of water in the lateral canal supplying the the distributary canal.

The canal operator will ensure that adequate water is available for water deliveries made from the distributary canal. He will operate the distributary off-take in such a manner that adequate diversions will be made through the distributary off-take when the depth of water in the lateral canal is at the low portion of the cycle. At other times, when the depth of water in the lateral is higher, the usually excessive diversion through the distributary off-take will increase. The result is increased volume of seepage and still greater volumes of farm and canal spill. The unit physical and physical conveyance efficiencies will be slightly and variably increased. Operational and conveyance may be significantly reduced, and the maximum conveyance efficiency will not be affected.

15. Fluctuations of the seepage characteristics of the distributary canal.

Certain distributary canals will exhibit fluctuating seepage rates caused by the diurnal withdrawals of water from the groundwater regime which governs the rate of seepage from the canal by phreatophyte vegetation. The water flow and depth variations, which occur as a result of these fluctuations, increases with length of canal affected. The canal operator accomodates these fluctuations by diverting sufficient water into the distributary canal to meet the maximum seepage rates occurring. At nightfall the groundwater level will recover and seepage from the canal will decrease. This additional water will be lost by increased farm spill, (as a result of increased water depths over quaternary off-takes), and by increased canal spill. The seepage fluctuations result in variable increases in unit physical and physical conveyance efficiencies, a significant but variable decrease in operational efficiency and a moderate decrease in conveyance efficiency. The maximum conveyance efficiency will exhibit a variable decrease. The moderate decrease in conveyance efficiency would result from the increased complexity of operating the distributary canal.

16. Technical competence of canal operators.

As the technical competence of canal operators increases, water losses by seepage, farm spill and canal spill decrease. The greater the understanding the canal operators have about the hydraulics governing distributary canal operations, the greater their capability to reduce water losses. With the exception of the maximum conveyance efficiency, all efficiencies which describe the performance of distributary canal operations would increase. The ultimate effectiveness of improved technical competence of

the canal operators to minimize losses is determined by senior management attitude toward the relative importance of reducing the water losses and the opportunities the canal operators are provided to utilize their increased technical competence.

7.0 Conclusions

The relationships between the factors which affect the irrigation water conveyance process and the performance of the irrigation conveyance system are very complex as has been demonstrated in previous chapters. Several of the factors have been examined in light of the detailed but qualitative examination of the operation of a small distributary canal, typical of those found in Southern Alberta. This analysis has clearly demonstrated how various changes to irrigation conveyance systems will impact on conveyance system performance. Of course, only trends can be predicted.

Quantitative predictions would require a quantitative approach. These analyses, however, could only provide qualitative guidance unless applied to specific irrigation conveyance systems of concern. Techniques by which this may be achieved are presented and discussed in Manz (1984).

8.0 References Cited

Manz, David H., (1984), Ph.D. thesis in preparation, "System Analysis of Irrigation Conveyance Systems", University of Alberta, Alberta.

POOR

QUALITY

ORIGINAL